Optical properties of water under high pressure

Laurent Weiss, Tazibt Abdel, Tidu Albert, Michel Aillerie

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L. Weiss[1,2,3], A. Tazibt[1], A. Tidu[3], M. Aillerie[2]

[1] Centre de Recherche, d'Innovation et de Transfert Technologique en Jet Fluide, 55000 Bar-le-duc, France
[2] Lorraine University & Supelec, Laboratoire Matériaux Optiques Photonique et Systèmes, LMOPS-EA 4423, Metz, France
[3] Lorraine University, Laboratoire d'Etude des Microstructures et Mécanique des Matériaux, UMR CNRS 7239, Metz, France
email: l.weiss@critt-tjfu.com

Summary

The refractive index and polarizability of water are precisely determined in the visible light range as a function of the pressure until 250 MPa by means of a new measurement technique and setup using special pipe tee included in an interferometer optical arrangement.

Introduction

The knowledge of physical properties of optical material often goes by the knowledge of its refractive index, which usually change with pressure, especially in liquid. To characterize the refractive index of a fluid taking into account the pressure, we have developed an interferometric set-up and technique for measuring the index variation of fluid up to 250 MPa. The measurements carried out on water have refined the Sellmeier and Tait equations allowing to link into one equation the wavelength, the pressure and the refractive index. Due to the Lorentz-Lorenz equation, the evolution of the polarizability as function as the pressure was also determined [1].
The developed technique can be used as a real time non intrusive sensor for measuring with high accuracy and without disrupting the flow, the physical properties of fluids such as pressure or density.

Discussion

The set-up is composed by two relatively independent parts. The first corresponds to the circuit of the liquid (here water) under test, the second to the optical interferometric arrangement. Both parts are coupled in a specially designed liquid-cell (Fig.1). The output photodiode which is located at a fixed observation point allows counting the number of scrolled fringes due to pressure variations controled by a transducer. Experiments were driven by a LabView® development.
Thus, we have determined the refractive index of pure water up to 250 MPa at different wavelength (Fig 2). This evolution confirms the results of Vedam's et al [2].

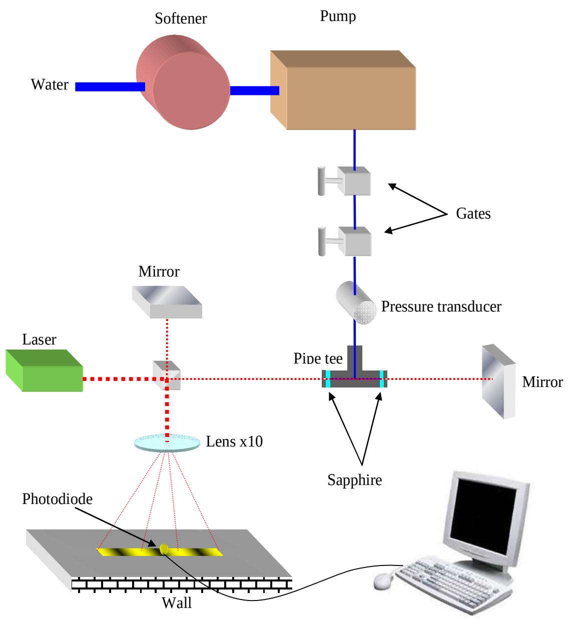

Fig 1. Experimental set-up

The fitting of the experimental curves was done by the Tait-Bradley-Pitzer (TBP) [3] and the Sellmeier equations [4] allowing, first, the TBP's coefficients variation as function as the wavelength and second, the variation of the Sellmeier's coefficients as function of the pressure. So we have rewritten both formulas to take into account the pressure/wavelength dependence. The error estimated by the discrepancy between experimental and fitted curves is found equal to 0.02 % for the TBP approach and 0.04 % for the Sellmeier one. Using the calculated values of the refractive index, we have used the Lorentz-Lorenz (LL) formula [5] to create the table of the polarizability with pressure and we have compared the results with the Looyenga's equation [6].

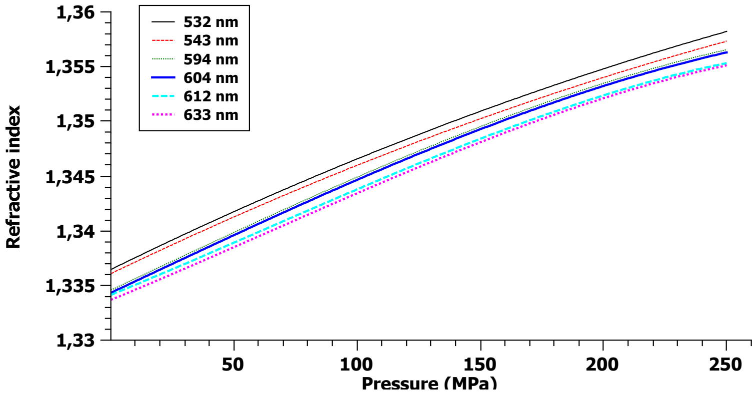

Fig 2. Refractive index as a function of pressure for various wavelengths

Finally, the above study allows us to propose a simple model (1) linking the refractive index, the wavelength and the relative density of a liquid in a pressure range up to high value.

$$d(\lambda,n) = (a_2\lambda^2 + a_1\lambda + a_0)e^{(b_2\lambda^2+b_1\lambda+b_0)n} \tag{1}$$

The maximal error on the relative density between the model (1) and the values given by the standard table [7] is equal to 0.19 % in the 0-250MPa pressure range.

Conclusion

We have shown that the three formulas, Tait-Bradley-Pitzer, Sellmeier and Lorentz-Lorenz can be considered as equivalent formulas for the determination of the refractive index of water in pressure range up to 250MPa. Nevertheless, with Tait-Bradley-Pitzer and Sellmeier equations, only the pressure is needed for the determination of the refractive index, while the polarizability or the density can be additionally determined by the Lorentz-Lorenz equation. Finally, the interferometric set-up can be use as a real time, high accurate and non intrusive density sensor for liquid under high pressure, via the Eq. 1 of the model.

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